Proceedings – 23rd Annual Conference – IEEE/EMBS Oct.25-28, 2001, Istanbul, TURKEY

MULTI-LAYERED LOSSY FINITE LENGTH DIELECTRIC CYLINDIRICAL MODEL OF MAN AT OBLIQUE INCIDENCE

S.S. Şeker , B. Yeldiren
Boğaziçi University, Dept. of Electrical-Electronics Engg.
80815 Bebek, İstanbul-Turkey
e-mail: seker@boun.edu.tr

Abstract: This paper is intended to give a simple electromagnetic formulation of the EM power absorption properties of multi – layered cylindrical model of man at RF frequencies and above. The formulation, however, has no limitations concerning frequency. Thus very low frequencies are also considered for comparison with the results in literature. Both horizontal and vertical polarizations are considered. A single general expression for model of man has been derived.

Absorbed power density of man against different values of incident power are illustrated at different frequencies and compared with ICNIRP standards.

1 Introduction

Recently, there has been an increase in public interest about possible biological effects of electromagnetic EM energy emitted by various electrical and electronic equipments. In response to this, experimental and modeling activities are increase to obtain a wide and reliable estimation of the EM levels.

In particular, a considerable amount of theoretical work has been devoted to the investigation of EM effects on human being using various shapes. Considerable discrepancies exist in the difficulty of numerically evaluating of the different models.[1-5]

The study of absorption properties for some three-dimensional models of man is interesting in practice, but in most of the real cases an exact calculation by analytical methods is impossible. Generally, the real models are approached with numerical techniques – finite differences, moment's method, finite element, etc. In most of the cases the starting point is the integral equations method. Though, where possible, analytic methods allow a better physical understanding of the problem. Another advantage of the analytical approaches is the possibility of testing the numerical methods.

In this paper, the circular multi – layered cylindrical model of man is studied, which is useful in three-dimensional modeling of man. This way a comparison to some numerical approaches may be possible, for testing. Thus the present investigation deals with the circular multi – layer finite-length cylinder at oblique incidence. An exact analysis is very difficult and laborious to carry out. As in any other physical problem it is necessary to introduce a simplifying assumption. Namely this analysis is based on the approximation that the internal fields induced within the finite-length cylinders are the same as those induced within the infinite -length cylinders having the same permittivity, orientation and diameter. These internal fields are then used to calculate the absorbed power densities in term of the radar cross section. To our knowledge this the first treatment of such a problem. The results apply when the minimum dimension of the cylinder's cross section is small compared with the cylinder length, although the length needs not be small compared with wavelength. The computed results are obtained, and compared with the results given in literature and good agreement was obtained for TE and TM polarizations. Numerical results are also obtained for low frequencies at normal incidence for comparison with previously published work in the literature. [1]

The methodology that is described in this paper is quite general and powerful. It provides a tool for determining absorbed power densities based upon material properties and geometric parameters. Because it is based upon analytic description of induced EM fields mechanism within each layer of material it is computationally very efficient in comparison with numerical approximation. It does not require the severe simplifying assumptions that are usually build into analytic descriptions. For model of man composed of several layers, this work provides a strong alternative to brute force numerical calculations. It is particularly useful for gaining insight into the material parameter and geometric constraints.

2 Theoretical Formulation

The magnitudes of the scattering and incident power densities are given by [2]

$$S_s = \frac{|E_s|^2}{2\eta_0}, \quad S_i = \frac{|E_i|^2}{2\eta_0} \qquad (1)$$

and η_o is the characteristic impedance of the free space. Absorbed power flux density by human model is $S_A = S_i - S_s$

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Multi-Layered Lossy Finite Length Dielectric Cylindirical Model of Man at Oblique Incidence	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) University, Dept of 80815 Bebek Y stanbul-Turkey	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 4	

or $S_A = S_i - a\sigma_{pq}$ (2)

where $\sigma_{pq} = 4\pi \left| f_{pq} \right|^2$, p, q∈ {v,h} is radar cross section (RCS), f is the scattering amplitudes and $a = \left[2\eta_0 4\pi R^2 \right]^{-1}$ is a constant. Thus from the last two equations one can see that radar cross section is the only important parameter determining electromagnetic power absorption properties of human. For finite length dielectric cylinder at oblique incidence, scattering amplitudes, f_{pq} are given as [1]

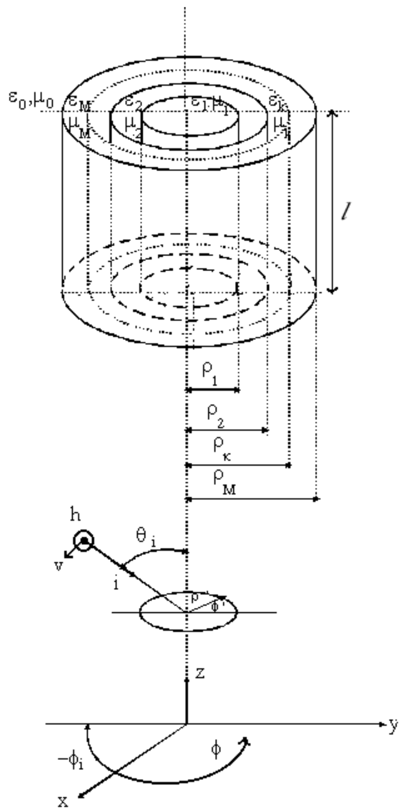

Figure 1. The geometry and the cross section of the cylinder.

$$f_{pq} = A\pi I_1 \sum_{n=-\infty}^{+\infty} j^n e^{jn(\phi_i - \psi)} \sum_{m=1}^{M} \chi_m$$

$$\begin{aligned}
&\Big\{ 2\left[\underline{p}.\underline{\underline{a}}_{mn} .\underline{q} I_{1mn} + \underline{p}.\underline{\underline{b}}_{mn} .\underline{q} I_{2mn} \right] \\
&+ \left[\underline{p}.\left(\underline{\underline{a}}^{s}_{mn} + j\underline{\underline{a}}^{c}_{mn} \right) \underline{q} I_{3mn} + \underline{p}.\left(\underline{\underline{b}}^{s}_{mn} + j\underline{\underline{b}}^{c}_{mn} \right) \underline{q} I_{4mn} \right] e^{j\psi} \\
&+ \left[\underline{p}.\left(\underline{\underline{a}}^{s}_{mn} - j\underline{\underline{a}}^{c}_{mn} \right) \underline{q} I_{5mn} + \underline{p}.\left(\underline{\underline{b}}^{s}_{mn} - j\underline{\underline{b}}^{c}_{mn} \right) \underline{q} I_{6mn} \right] e^{-j\psi} \\
&+ \left[\underline{p}.\left(\underline{\underline{c}}^{s}_{mn} + j\underline{\underline{c}}^{c}_{mn} \right) \underline{q} I_{7mn} + \underline{p}.\left(\underline{\underline{d}}^{s}_{mn} + j\underline{\underline{d}}^{c}_{mn} \right) \underline{q} I_{8mn} \right] e^{j\psi} \\
&+ \left[\underline{p}.\left(\underline{\underline{c}}^{s}_{mn} - j\underline{\underline{c}}^{c}_{mn} \right) \underline{q} I_{9mn} + \underline{p}.\left(\underline{\underline{d}}^{s}_{mn} - j\underline{\underline{d}}^{c}_{mn} \right) \underline{q} I_{10mn} \right] e^{j\psi} \Big\}
\end{aligned}$$

(3)

Where $A = k_0^2 / 4\pi, \chi_m$ is the relative susceptibility of the m[th] cylinder layer, $\underline{q}$ is the unit polarization vector, ρ_M is the radius of the outermost cylinder and M is the total number of layers beginning from m=1. I_{1mn} to I_{10mn} are integrals of Bessel's functions. Also $\psi = \arctan(\beta_2 / \beta_1)$, $\overline{\phi_s} = \phi - \phi_s$ where

$\beta_1 = \cos\overline{\phi}_s \sin\theta_s$

$\beta_2 = \sin\theta_s \cos\theta \sin\overline{\phi_s} - \cos\theta_s \sin\theta$

The expressions in eq. (3) $\underline{\underline{a}}, \underline{\underline{b}}, \underline{\underline{a}}^k, \underline{\underline{b}}^k, \underline{\underline{c}}^k, \underline{\underline{d}}^k, k \in \{c, s\}$ are obtained by applying the boundary conditions an each layer boundary of the multi-layered cylinder.

In order to check the correctness of the scattering amplitude, the multi – layer infinite length cylinder and the single layer cylinder are considered as special cases. Both cases the results are exactly the same as that given of ref. [3] where the experimental validation is also shown.

3 Results and Discussion

In the application of a given theory to practical computations, special care was exercised in ascertaining the limit of validity of the theory.

Eq. (3) gives us how much power transmit to human beings in terms of only one measurable parameter which is RCS. It can be measured easily in any radar laboratory.

In this part, the absorption characteristics of multilayered cylindrical model of man exposed to electromagnetic (EM) plane wave with oblique incidence has been investigated.

The amount of electromagnetic energy absorbed by exposed person depends on the physical characteristics of the human body; its size, shape and composition (i.e. relative percentages of muscle fat, bone, blood and soft tissue). The frequency determines the mechanism of absorption within the body.

The results are obtained for 900MHz, 1800MHz and 2450MHz. These frequency values are chosen because of practical usage of them in daily life. 900 and 1800MHz are commonly used frequencies by GSM (Global System for Mobile Communication) networks. 2.45GHz is chosen because it is widely used for microwave ovens in the market.

Table 1. gives the parameters used for each tissue layer of man [4], considered in simulations. For the five layer model of man the fourth layer is considered to be air of thickness 6 mm. and the fifth layer is taken to be humid clothing with complex permittivity $\varepsilon_r = 10 - j5$ for all frequencies [5]. The length of human has been taken as 1.7m.

	ε_r	σ (S/m)	Thickness (m)
Skin	29.10	2.08	0.002
Fat	5.61	0.112	0.01
Muscle	50.63	1.56	0.1008

Table 1. Parameters of the different tissue layers.

Next we consider power absorption of human body in terms of international standards. Public exposure limits are given in Table 2. determined by International Commission on Non - Ionizing Radiation Protection, ICNIRP.

	Mobile phone base frequency		*Microwave oven frequency*
Frequency	900MHz	1800MHz	2450MHz
	Power density (W/m^2)	Power density (W/m^2)	Power density (W/m^2)
Public Exposure Limits	4.5	9	10

Table 2. ICNIRP standards.

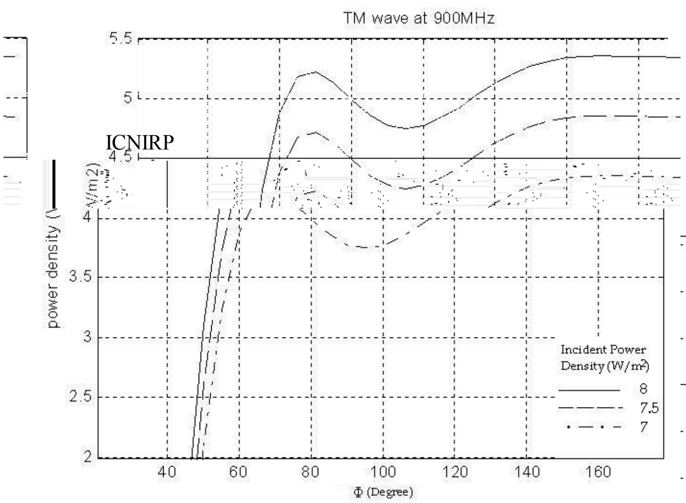

Figure 2. Absorbed power density vs. different values of incident power for model of man. Figure shows the TM wave at 900MHz.

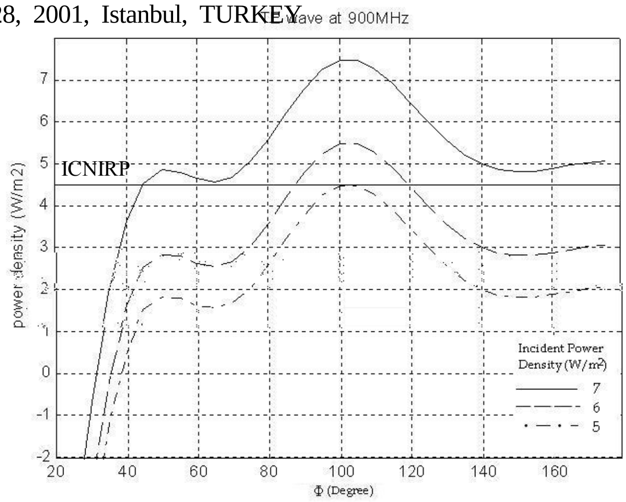

Figure 3. Absorbed power density vs. different values of incident power for model of man. Figure shows the TE wave at 900MHz.

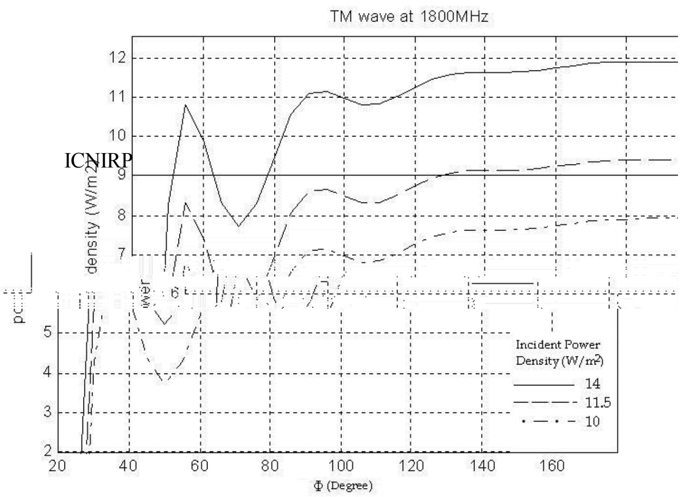

Figure 4. Absorbed power density vs. different values of incident power for model of man. Figure shows the TM wave at 1800MHz.

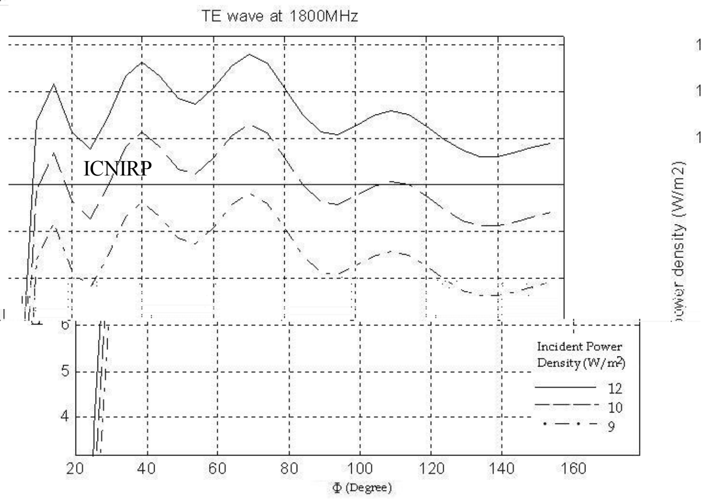

Figure 5. Absorbed power density vs. different values of incident power for model of man. Figure shows the TE wave at 1800MHz.

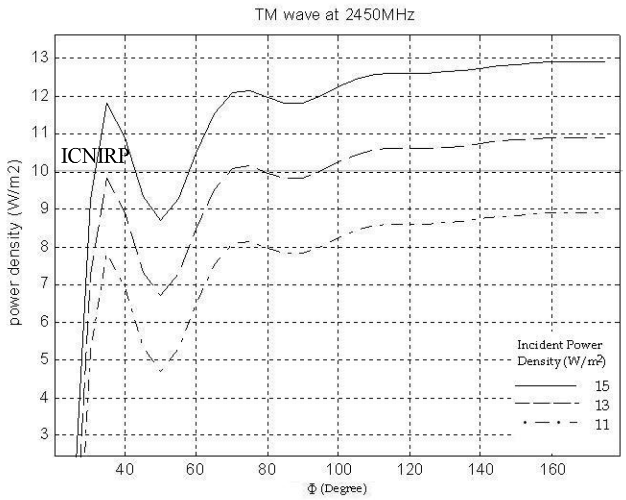

Figure 6. Absorbed power density vs. different values of incident power for model of man. Figure shows the TM wave at 2450MHz.

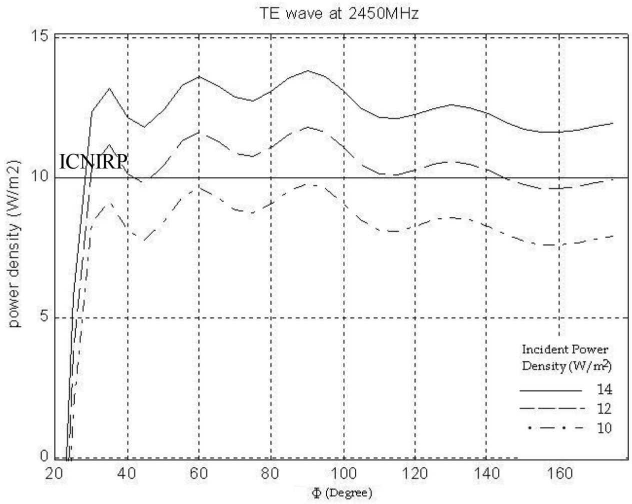

Figure 7. Absorbed power density vs. different values of incident power for model of man. Figure shows the TE wave at 2450MHz.

In addition to the figures above, the same graphs was also plotted for three – layered model of man for a comparison with graphs of five – layered model. As a result of this comparison, it can be said that although graphs of three – layered model are smoother and average power densities of two different models are almost same, five – layered model of man gives more realistic approaches to the human modeling.

4 Conclusions

At frequencies around and greater than 10 GHz, the depth of penetration of the field into tissues is small and SAR is not good measure for assessing absorbed energy; the incident power density of the field is more appropriate dosimetric quantity [6]. This study reflects this conclusion.

This work can be considered as a generalization of the previously work done on cylindrical model of man with both vertical and horizontal polarizations and oblique angles of incidence and with no restrictions on the frequency considered.
It is generally acknowledged that several studies have reported increased cancer risks, especially for children living closer to high – power electrical and electronic equipments. The comparison of the given figures allows us for a determination of EM wave source power according to ICNIRP standards.

5 References

1. Seker, S., I. Akkaya and C. Utku, “Differential Cross Section of Multi - layered Lossy Cylinder of Finite Length” *Progress in Electromagnetics Research*, PIER 18, 151-171, 1998.
2. Ishimaru, A., *Wave Propagation and Scattering in Random Media,* Vol. 1, 9-41, Academic Press, 1978.
3. Bussey, H. E. and Richmond, “Scattering by a lossy dielectric circular cylinder of finite length”, *IEEE Trans. Antenna and Prop.,* Vol. AP-36, No.2, 303-307, 1988.
4. J.C. Lin, “Handbook of Biological Effects of Electromagnetic Fields”, *CRS Press*, 1979.
5. H. Massoudi, C.H. Durney, W. Barber and M.F. Iskander, “Electromagnetic Absorption in Multilayered Cylindirical Models of Man”, *IEEE Trans. Microwave Theory Tech.,* Vol. AP 23, Sept. 1975, pp 723 – 725.
6. ICNIRP Guidelines, Health Physics, Vol. 74 (4), 494 – 5, 1998

Acknowledgement: This work was supported by B.U. Research Foundation Project No: 00A201.